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Aircraft in current use in IAF are restricted to a maximum upper limit of 8g with capability to sustain about 5.5g for long periods (30-40 seconds). Aircraft of the future and already being introduced into service in other Air Forces of the World have much higher + Gz capabilities. Such aircraft are likely to be flown at sustained high accelerations i.e., above 6.5g for 45 seconds and more. The pilots will have to be preselected, trained and adequately protected to enable them to cope with this high stress. Various protective techniques have been proposed and are being tried out. Work done at IAM Bangalore with positive pressure breathing as a protective technique has been discussed in this paper. The study shows the benefits of using 20mm Hg PPB as a protective technique for high sustained G.

High Sustained Positive G - Future Problems and Solutions

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THE main purpose of Aviation Medicine as a discipline is to enhance pilot performance in aircraft. The need for protection of pilots from the effect of high + Gz in aircraft has been felt all along for the last 40 years or so, but the problem is becoming more complex and demanding because the future generation of aircraft will have much higher G limits and hence a spurt of research work in this field.

Now we are confronted with aircraft designs which will be capable of producing appreciably higher G loads for extended durations. Because protection given by anti g suits cannot be increased appreciably an adequate solution must be found. Some of the aircraft of 1980s (F - 14, F - 16 and F - 18) will have considerably higher load factors and manoeuvreability than the present generation aircraft. These aircraft will have low wing loading and high thrust to weight ratios and in order to make full use of these aircraft the aircrew will have to tolerate higher g loads than in current aircraft. It is therefore an urgent goal to find means to improve g tolerance of pilots.

Several methods have been in use and are being improved upon, but there is a limit to such improvements. New ideas and approaches have been mainly in the form of respiratory manoeuvres like M1 and L1, positive pressure breathing (PPB) and tilt back seats. Some recent work in this field has shown the possibility of use of PPB as a means of protection, but the modalities and exact pressures to be used are not well understood. This study has been undertaken to further understand and define the utility of PPB in +Gz protection.

Positive Pressure Breathing

Positive pressure breathing has been in use as a means of protection against hypoxia at altitudes above 12,192m, (40,000 ft). Study of effects of PPB with and without counter pressure has been conducted by many workers but the pioneering work of Ernsting[3] has been most exhaustive.

Systemic arterial pressure is always increased with PPB, although the rise in blood pressure (BP) is related to PPB and depends on the degree of counterpressure applied. This rise of BP is due to direct transmission of the rise of intrapleural pressure to the left ventricle and the systemic arteries within the thorax and abdomen.

The steady state increase in BP induced by PPB is slightly less than the PPB even with the use of counter pressure to the trunk. This slight decrease of BP is due to the reduction in effective blood volume and thus reduction in cardiac output. Counterpressure to the limbs reduces the fall in effective blood volume and so the mean arterial and pulse pressures are raised. Application of chest counterpressure also increases the arterial pressure at a given PPB by reducing the lung distension and thus producing a greater increase in intrapleural pressure. At low PPB, i.e., below 30mm Hg this is of greater significance because large fraction of the applied breathing pressure may be expended in overcoming the elastic recoil of the lungs. It is estimated that the first 8mm of PPB is lost in overcoming the elastic recoil of the lung [3,5].

The increase in arterial pressure and fall in pulse pressure is not due to rise of intrapleural pressure and the fall of cardiac output alone PPB induces a marked increase of peripheral resistance as in the valsalva manoeuvre Peripheral resistance in the forearm is nearly doubled at 60mm Hg PPB with trunk counterpressure. There is a generalised arterial constriction in PPB which tends to maintain high arterial pressure even with falling cardiac output This reflex increase in peripheral resistance probably arises from the receptors in the low pressure regions of the intrathoracic circulation, aortic and carotid sinus regions [3,5].

In most exposures to PPB where both lower limb and trunk counter pressure is applied, the rise in mean BP is higher than the PPB applied[3]. In PPB it is not only a rise in mean BP but a concomitant rise in venous pressure. The rise in venous pressure is helpful in increasing the venous return. This process is further improved with the use of lower limb counterpressure by an anti-g suit.

PPB as a protection against +Gz

Various methods of raising intrapleural pressure, e.g., yelling, shouting, grunting, tensing of abdominal muscles, M1 & L1 manoeuvre, have been regularly utilised by pilots to increase their tolerance to +Gz. The M1 manoeuvre which is a combination of most of the above techniques, has shown a large increase in +Gz tolerance [2,4,7] (around 1.5g). But this manoeuvre produces marked fatigue, requires constant practice to reduce its distracting effect on pilots and if improperly practised could lead to a fall of BP during the inspiratory phase[5]. To overcome the above problems and realising that PPB also raises the mean BP, PPB has been tried out [11] as a means of protection against +Gz stress.

Materials and Methods

Subjects : Ten fighter pilots in the age group 21-35 years with mean age of 28 years were exposed to +Gz on the human centrifuge. All the subjects were in medical category AI GI (fully fit to perform flight duties). They were given a thorough physical

examination after ascertaining their physical and mental well being on the day of the tests. The medical examination included pulse, blood pressure, general physical examination and systemic examination of the cardiovascular system, respiratory system and abdomen.

Flying experience : The test subjects had flying experience between 115 to 2500 hrs on fighter aircraft. Except for two subjects, all others had nearly 1000 hours of flying experience in fighter aircraft. All of them had used anti-g suits and personal protective manoeuvres during high +Gz forces as a routine.

Centrifuge experience : Eight out of these ten subjects had undergone trials on the human centrifuge previously. Four test pilots had earlier taken part in human centrifuge trials for assessment of anti-g suits. Thus the subjects had very wide experience of +Gz forces in flight and on the human centrifuge to get repeatable and consistent results.

Experience of PPB : All the 10 subjects had undergone exposures upto 30mm Hg positive pressure breathing during the high performance medical examination. Many of them had repeatedly gone through PPB indoctrination and training during their service career. However, all of them were given 4-5 exposures at + 20 and +30mm Hg PPB at rest, till they feltcomfortable and accustomed to this stress. They were asked to practise speaking during PPB exposure. The switching ON & OFF of the PPB from the regulator was practised till each subject felt confident of completing the manoeuvre during centrifuge trial runs. After this training all subjects were able to breathe at normal rate with PPB and were quite comfortable.

Human Centrifuge : The subjects were tested on the IAM human centrifuge having a test radius of 5 meters. The subject is seated in a gimbal mounted gondola with an aircraft seat with a back rest inclination of 13° from the vertical. The subject is monitored on close circuit TV and has two way voice communication with the medical controller. The subjects were instrumented for ECG recording for CM5 lead

Oxygen system : A MK 20A pressure demand oxygen regulator was modified to deliver 10, 20 & 30mm Hg of PPB. Each subject was trained to put the oxygen regulator on at the start of +Gz exposure. The subjects wore a P;Q oxygen mask with a matching inner helmet (G helmet). The system was tested for leaks and the pressures delivered were measured with a mercury manometer. All subjects were provided with a properly fitting partial pressure (PP) suit (Capstan type) after cardinal body measurements. Counterpressure to the lower limbs during +Gz exposures was provided by anti g valve (AD-6E) set at high position.

PLL technique : The standard IAM technique[9]-[10], [11], [12] for PLL determination with one central red light and two peripheral lights set at 53° was utilised in this project. A modified system with multiple lights set at 64, 60, 56, & 52° was also utilised in this trial; but PLL at 52° was used as the end point.

Test profiles used : All the subjects were exposed to increasing values of +Gz at the onset rate of 0.5g/sec and steady period of 20 secs with a decay rate of 0.1g/sec

Type A run for determination of resting unprotected PLL value with the subject wearing the PP suit but not connected to the anti-g valve.

Type B run for determination of resting PLL with anti g suit protection (anti g suit part of the PP suit was used). The suit was connected to the AD-6E anti g valve set at maximum setting

Type C runs were used to find out the PLL value with PPB of different magnitude. Type C (i) runs were with PPB of 10 mm Hg. Type C(ii) runs with 20mm Hg PPB and Type C(iii) runs with 30mm Hg PPB

Medical examination post run, was carried out to check for pedal oedema, petechial haemorrhages on feet and back and lung base atelectasis in all cases.

Subject comments were obtained on a proforma post run from all subjects

Results

The subject particulars and details of branch, age, flying experience, medical category and total number of trial runs completed by each are given in table I. Ages ranged from 21-35 years with mean 27.9 years. All of them were F(P) officers with wide experience on fighter aircraft ranging from 115-2500 hours with a mean 1028 hours. Except for two young officers all of them had around 1000 hours of flying to their credit. All of them had completed the high performance medical examination at IAM, including an experience of positive pressure breathing. Eight of these subjects had flown high performance aircraft for 500 hrs or more. They had undergone PPB experience on ground testers a number of times. The subjects were exposed to between 8-16 runs on the centrifuge with an average of 12 runs each.

Table - I

Subject Particulars

Sl No.	Age (Yrs)	Flying experience on fighter a/c hours	Total No. of Trial runs
1	35	2500	11
2	31	1300	8
3	27	1100	8
4	29	1400	15
5	21	140	10
6	28	1000	15
7	26	425	13
8	21	115	16
9	34	1400	13
10	27	900	12
Mean	27.9	1028	
Range	21-35	115-2500	

In view of the vast flying experience the subjective reports and opinions of these subjects after the trial have been given a lot of weightage and credence. The previous experience with repeated high +Gz exposures and centrifuge trials was very useful in getting proper and repeatable results.

The PP suit was tested on the ground inflation test rig for leaks. The relaxed unprotected tolerance +Gz (Type A run), tolerance with PP suit inflated (Type B run) and tolerance with 20mm and 30mm PPB (Type C (ii) & (iii)) are given in Table II. The relaxed unprotected tolerance (Type A) varied between 3.5-4.7g with mean of 4.27 with SD = 0.39.

The tolerance of these subjects with PP suit (Type B) ranged between 4.5-5.7g with a mean value of 5.3 and SD = 0 33. The mean protection afforded by the PP suit was 1.03g (range 0 9-1.3). The increase in tolerance is highly significant by 't' test

The subjects showed a mean tolerance of 5.7g with 20mm PPB and PP suit (type C (ii)) with a range of 4.6-6.4g and SD of 0.48. The mean increase of g tolerance with 20mm PPB, i.e , [type C (ii)] run over type B run was 0.44g which is significant by 't' test.

Tolerance of subjects with PP suit and 30mm PPB (Type C (iii) run) ranged between 4.9-6.6g with mean 6.1 and SD 0.50. The mean increase in tolerance between 20mm and 30mm PPB (Type C (ii) and Type C (iii) runs) was 0 36g. This difference is significant by 't' test.

The difference of g tolerance between 30mm PPB (Type C iii) and PP suit (Type B run) is 0.8g which is highly significant. Overall increase from relaxed tolerance to protected tolerance with 30mm PPB (Type C (iii) run) is 1.83g and with 20mm PPB (Type C (ii) run) is 1.47g.

Table III gives the results of post run complaints and comments of the subjects. Subjective comments comparing PPB experience with personal protective methods, 20 and 30mm PPB and intercommunication during PPB are also given in Table III.

Table - II

+Gz Tolerance Values

Subject No.	Type A PLL Relaxed	Type B PLL with PP suit	Type C (ii) PLL with suit +20mm	Type C (iii) PLL with suit +30mm
1	4.7	5.7	6.0	6.3
2	3.5	4.5	4.6	4.9
3	3.8	5.1	5.4	5.6
4	4.6	5.6	6.4	6.6
5	4.4	5.4	5.6	6.3
6	4 0	5.3	6.1	6.6
7	4.5	5.4	5.7	6.2
8	4.2	5.2	6.0	6.2
9	4.6	5.5	5.8	6.1
10	4.4	5.3	5.8	6.2
Mean	4.27	5.30	5.74	6.10
SD	0.39	0.33	0.49	0.51
Range	3.5—4.7	4.5—5.7	4.6—6.1	4.9—6.6

Mean difference between A & B = 1.03 ($P < 0.001$)

Mean difference between B & C (ii) = 0.44 ($P < 0.001$)

Mean difference between C (ii) & C(iii) = 0.36 ($P < 0.001$)

Mean difference between B & C (iii) = 0.80 ($P < 0.001$)

Table - III

Subjective Complaints and Comments

Sl No.	Complaints	The better between PPB & personal effort	20mm or 30mm	Transmission possible
1	Nil	Personal effort	20mm	At 20mm only
2	Nil	PPB	20mm	At 20mm only
3	Too much pressure on abdomen	PPB	20mm	Better at 20mm
4	Nil	PPB	20mm	Better at 20mm
5	Nil	PPB	20mm	At 20mm only
6	Nil	PPB	30mm	Better at 20mm
7	Nil	Personal effort	20mm	Only at 20mm
8	Nil	PPB	20mm	Only at 20mm
9	Nil	PPB	20mm	Only at 20mm
10	Nil	PPB	20mm	Better at 20mm

Only one subject (No. 3) complained of excessive pressure in abdominal bladders. He was uncomfortable in the last 4 out of 10 runs that he went through. All other subjects felt quite comfortable during the test runs and had no complaints.

Eight out of the 10 subjects preferred PPB of 20mm to personal protective methods, to reduce fatigue and discomfort. Only two subjects preferred their voluntary protective methods over PPB. They also said that probably regular training with PPB will change their opinion.

Nine subjects showed definite preference for 20mm PPB over 30mm PPB because of the comfort and convenience of the lower pressure. They felt that the increase of g tolerance by about 0.5g was welcome with this lower pressure. Only one subject was in favour of 30mm PPB despite the discomfort, since it gave a large increase in tolerance (0.5g) in his case.

Subjects had tried to transmit during PPB exposure. All the 10 subjects could transmit at 20mm PPB and all of them felt that transmission is better at 20mm PPB. All the aircrew gave a lot of stress on the problem of transmission during PPB. They felt that PPB higher than 20mm will not be acceptable due to this handicap.

One subject (No. 3) showed petechial haemorrhages on both feet. He had felt excessive pressure in the leg and abdominal bladders. On examination the PP suit was found to be too tight around the legs. He had been fitted with size 1 PP suit although he was tall enough for size 2/3. This was done in view of his girth measurements being very low. None of the subjects had pedal oedema or any findings in the lung bases.

Discussion

The relaxed unprotected grey out tolerance of these 10 subjects was mean 4.27g with SD 0.39. This tolerance value compares very well with the reported[4,8] PLL tolerance in fighter pilots of this age group. The tolerance values quoted by Gillingham[4] for Naval aviators are also in the same range i.e 4.1±0.7g for grey out at 48°.

The mean tolerance of these subjects wearing PP suit and inflated by the anti g valve was 5.3g with SD=0.33 (range 4.5—5.7g), The mean increase in g tolerance with the use of the PP suit was 1.03g (range 0.9—1.3g). This increase in tolerance is quite close to but lower than the average tolerance increase given by cutaway type and combined anti g suit cum overall suit[10]. The average protection by cutaway suits was 1.35g and by combined suit was 1.3g. This slightly lower amount of protection was rather unexpected, In another comparison carried out at IAM the protection given by the capstan suit and cutaway anti g suit was found to be 0.5g and 1.3g (difference 0.8g.)

In the present study one fact may have altered the apparent tolerance increase since the subjects wore the suit even though not inflated during the type A runs also. It is known[10] that cutway anti g suit when worn uninflated provides an additional benefit of about 0.3g over the relaxed unprotected g tolerance. Since the PP suit is a tighter and better fitting garment than the cutaway anti g suit this increase in tolerance will be if anything larger and it was 0.4g in an earlier study[15]. Thus we can accept that the actual production by an inflated PP suit will be around 1.4g. This is quite good and comparable to any good anti g suit in use in the World.

Positive Pressure Breathing :

PPB has been tested as a protective method to increase tolerance to +Gz by a few workers [6,13,14,15] so far. There has been a consistent increase in tolerance with less fatigue in these trials especially when compared with the M1 & L1 manoeuvres practised by pilots. There has been no agreement on the amount of pressure to be used for such protection. Most trials[13, 14] have been with 30 or 40mm Hg PPB because of the common knowledge that PPB upto 30mm Hg can be well tolerated for reasonably long periods, even without counter-pressure. No work has been completed with variable pressures. In this study 3 different pressure have been tested, i.e., 10, 20 and 30mm PPB.

Available literature[3,5,12] shows that increase in mean arterial pressure is larger, nearly equal to PPB value, when the chest is supported by a counter pressure garment. By using a counter pressure garment very little pressure is 'wasted' in overcoming the elastic recoil of the lung and thus the intrapleural pressure rise is the same as the applied pressure to the respiratory tract.

In this study, counterpressure has not been used but the capstan partial pressure suit of Russian origin is so designed that a fully adjusted suit is quite tight even when not inflated. Wearing such a suit, a subject has some external support to the chest wall. This will prevent undue expansion of the chest. To what extent this factor has inhanced the beneficial effect of PPB with a PP suit cannot be stated with certainty, but this indirect advantage was kept in mind while planning the study.

10mm Hg PPB—Type C (i) run :

In this study, the first 3 subjects were tested with 10mm PPB after the PP suit protection run. There was no change in tolerance to PLL. All these subjects commented that they felt no additional advantage with this pressure Since the subjects were going through additional runs with no definite information or advantage, this profile was later on given up.

20mm Hg PPB - Type C (ii) run

All the 10 subjects were exposed to increasing levels of +Gz with 20mm Hg PPB in this series They have all shown an increase in tolerance and the mean increase is 0.44g over type B run. This is significant by 't' test The subjects preferred 20mm Hg PPB because of the ease of transmission on intercom, no strain or fatigue while breathing and the advantage of higher tolerance than anti g suit protection alone. Subjectively practically all (nine) subjects preferred 20mm over 30mm PPB exposure. 8 subjects preferred the 20mm PPB over their usual voluntary protective methods. This is a significant finding since most pilots are not very keen to give up old habits like the voluntary tensing manoeuvres.

At moderate levels of g, ie, below 6g, protection with 20mm PPB will obviate the necessity of voluntary protection. Most current aircraft do not go through higher values of g for sustained periods of 15 second or more. Thus introduction of a modified oxygen regulator which delivers PPB during g manoeuvres may become the method of choice in future.

The discomfort of breathing at 20mm Hg PPB is so slight that very little training if any, will be required by pilots converting to this new system. Moreover the essential requirement of talking during combat manoeuvres is better fullfilled by this pressure than by 30mm Hg PPB

30mm Hg PPB-Type C (iii) run

All the subjects were exposed to 30mm Hg PPB runs. The average increase in +Gz tolerance over the 20 mm Hg stage [type C (iii) - Type C (ii)] was 0.36g. This increase in tolerance is statistically significant. It is a 75% increase over the protection given by 20mm Hg PPB. This gain in tolerance by an additional 10mm Hg of PPB reveals that as the PPB increases a large part of the pressure is conveyed to the intrapleural space and it raises the mean arterial pressure by the same amount.

The total advantage of 30mm Hg PPB over the anti g suit protection alone [type C (iii)-Type B run] is 0.84g which is a very significant increase. This pressure is quite adequate to protect pilots in current generation aircraft where sustained accelerations beyond 6g are practically never experienced. Provision of the option of 30mm Hg PPB during +Gz exposures would totally eliminate the requirement of personal straining manoeuvres

Even though the tolerance increase is larger with 30mm, 9 subjects preferred 20mm to the higher pressure. The factors which weighed in their minds were lesser fatigue, less discomfort in breathing, ease of speaking and transmitting at 20mm and adequate protection for current aircraft requirements. Only one subject found 30mm PPB acceptable and preferable over personal straining techniques.

Subjective fatigue and preferences

All the subjects in this study were experienced fighter pilots who have shown preferences for 20mm Hg PPB over personal protective measures in use currently. They all felt that fatigue is lesser with 20mm Hg PPB than with other measures. Most of these subjects have shown preference for 20mm rather than 30mm PPB. Difficulties in transmission on RT with 30mm Hg PPB was emphasised by practically all the subjects.

Conclusions

The positive pressure breathing used in this trial has shown significant increased tolerance with relaxed g exposures. 10mm Hg PPB does not offer any additional protection over the PP suit tolerance. PPB of 20mm Hg gives an additional protection of 0.44g which is significant and quite adequate to protect pilots in current aircraft without any need to resort to personal protective measures. PPB of 30mm Hg gives an additional protection of 0.36g over the 20mm Hg trial. This gain in relaxed tolerance is significant. In aircraft requiring high g protection for long periods this level of PPB may be required. Ten subjects, all experienced fighter pilots who took part in these trials have commented favourably on the PPB as a means of protection during relaxed +Gz exposures. Nine out of these 10 subjects have preferred 20mm Hg PPB over 30mm Hg. Problems of transmitting during 30mm Hg PPB were highlighted by all the subjects.

Fatigue produced by PPB, 20mm and 30mm Hg was subjectively lesser than the personal protective measures like tensing of muscles yelling and shouting. All subjects realised and accepted that the PPB offers a good additional method of increasing tolerance to +Gz. This method could be utilised routinely and personal protection resorted to in still higher +Gz situations. PP suit was adversely commented upon in terms of its discomfort of donning, higher heat load and problems of upkeep of this suit. All subjects would prefer to use the conventional 5 bladder cutaway suit for g protection rather than the PP suit.

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